Sunday Afternoon, October 19, 2008

IPF 2008 Frontiers in Imaging: from Cosmos to Nano
Room: 312 - Session IPF-SuA

Astronomical Imaging

Moderator: L. Hartmann, University of Michigan

3:00pm **IPF-SuA1 Large Telescope Projects**, ***R. Bernstein***, University of California, Santa Cruz **INVITED**

Over the last 150 years, the diameter of the largest operating telescope has doubled every 30 years. The last generation of telescopes (6-10 m diameters) have been in scientific operation for about a decade. While those projects faced a number of optical and structural challenges, the success of the next generation of telescopes depends not only on conquering the technological challenges that come with scaling up large structures, but also on controlling costs and achieving new standards in image quality through active controls and adaptive optics. In this talk, I will discuss some of the challenges associated with building and operating the next generation of "Extremely Large" Telescopes (ELTs).

3:40pm **IPF-SuA3 Instrumentation for Large Telescopes**, ***D. Fabricant***, Harvard-Smithsonian **INVITED**

In the past 25 years, the application of new technologies has transformed instrumentation for large, ground-based telescopes. These technologies include the development of large optical and infrared array detectors, newly available large crystalline and optical glass lens materials, and high speed robotics. Harnessing these technologies requires a high level of sophistication in engineering and applied physics, including optical, thermal, structural, and control system design. I describe state-of-the-art instruments for imaging and spectroscopy now operating at large telescopes, and look forward to our plans for the next generation of extremely large telescopes.

4:20pm **IPF-SuA5 Adaptive Optics in Astronomy**, ***B.L. Ellerbroek***, TMT Observatory Corporation **INVITED**

Adaptive optics (AO) is a technology for the real-time correction of the optical aberrations experienced by light waves as they propagate through atmospheric turbulence and similar distorting media. AO is now used at numerous ground based astronomical observatories, and currently obtains (for many applications) image quality which approaches what could be achieved with the same aperture diameter in space. The benefits of AO increase dramatically with telescope size; for the future generation of extremely large telescopes, the benefits of AO may be as great as 100 times larger than can be obtained with existing telescopes on account of the factor of 10 advantage in collecting area. In this presentation, we will briefly review the fundamentals of adaptive optics, illustrate some of the astronomical results which have been achieved using AO to date, summarize the recent advances in component technologies and system concepts which enable the implementation of AO on future extremely large telescope, and finally, describe the designs and expected performance of the “first light” AO systems for the Thirty Meter Telescope project.

5:00pm **IPF-SuA7 Imaging with Near-infrared Interferometers**, ***J.D. Monnier***, University of Michigan **INVITED**

Under the best conditions, telescope diffraction limits the angular resolution for astronomical imaging. Using interferometry, we can coherently combine light from widely-separated telescopes to overcome the single-telescope diffraction limit to boost our imaging resolution by orders of magnitude. I will review recent technical advances combining four telescopes of the CHARA Array on Mt. Wilson, CA, with baselines of 330 meters allowing imaging with sub-milli-arcsecond resolution. I will present the first resolved images of main sequence stars besides the Sun and show first results imaging interacting binary systems.

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Bio-Imaging

Moderator: J. Hollenhorst, Agilent Technologies

8:20am **IPF-MoM1 Trapping Single Molecules in Water at Room Temperature**, ***A.E. Cohen***, Harvard University **INVITED**

To study a single molecule, one would like to hold the molecule still, without perturbing its internal dynamics. I will present a machine that achieves this goal. The Anti-Brownian Electrokinetic trap (ABEL trap) tracks the Brownian motion of a single molecule using fluorescence microscopy, and applies electrical kicks to the molecule that are timed to induce an electrokinetic drift that cancels the Brownian motion.[1] The ABEL trap can immobilize single biomolecules for extended observation and has been used to study the dynamics of individual DNA molecules and protein chaperonins.[2] I will give examples of new things that can be learned from trapped molecules.[3]

[1] A. E. Cohen and W. E. Moerner, "Suppressing Brownian motion of individual biomolecules in solution," Proc. Natl. Acad. Sci. USA 103, 4362-4365 (2006).

[2] A. E. Cohen and W. E. Moerner, "Principal Components Analysis of shape fluctuations of single DNA molecules," Proc. Natl. Acad. Sci. USA 104, 12622-12627 (2007).

[3] A. E. Cohen and W. E. Moerner, "Controlling Brownian motion of single protein molecules and single fluorophores in aqueous buffer," Opt. Express 16, 6941-6956 (2008).

9:00am **IPF-MoM3 Pushing Magnetic Resonance Imaging Into the Nanoscale Regime - the Quest for a Molecular Structure Microscope**, ***D. Rugar***, IBM Research Division **INVITED**

I describe our effort to extend magnetic resonance imaging (MRI) into the nanometer regime using a technique called magnetic resonance force microscopy (MRFM). MRFM achieves a billion-fold improvement in the sensitivity of magnetic resonance detection by replacing the conventional inductive pickup with ultrasensitive detection of magnetic force. This increase in sensitivity can be harnessed to greatly improve the resolution of magnetic resonance microscopy. In a series of recent experiments at IBM, we have successfully demonstrated 3D magnetic resonance imaging with spatial resolution on the order of 5 nm. The experiment operates in field gradients up to 50 gauss per nanometer (5 million tesla per meter) and makes use of the naturally occurring statistical polarization of nanoscale ensembles of nuclear spins. Understanding the unusual point spread function of MRFM is key to converting the measured 3D force map into a real-space image of the proton distribution in the sample. As a first demonstration of 3D nanoscale MRI, we have imaged individual tobacco mosaic virus particles. The long term goal of this work is to develop a "molecular structure microscope" whereby one could directly image the 3D atomic structure of macromolecules.

10:20am **IPF-MoM7 Imaging in Cell Biology**, ***T. Kirchhausen***, Harvard Medical School **INVITED**

11:00am **IPF-MoM9 Intracellular Fluorescence Imaging at Nanometer Resolution**, ***H.F. Hess***, Howard Hughes Medical Instituite **INVITED**

Fluorescence microscopy, is usually limited in its ability to resolve and focus on features smaller than the optical diffraction limit. However special photoactivated fluorescent proteins can be harnessed in a technique called Photo-Activated Localization Microscopy, PALM. Successive sparse subsets of these fluorescent proteins can be activated, imaged, individual molecules localized and their coordinates accumulated and rendered into a PALM image. Thereby the distribution of labeled endogenous proteins can be seen with the resolution of an electron microscope. PALM images of protein location and organization are illustrated with mitochondria, lysosomes, actin networks, focal adhesions and other cell structures. Another technique, an interferometric microscope, is described that can measure the vertical position of fluorescent molecules to nanometer precision with high photon efficiency. This can be combined with PALM to give full 3 dimensional molecular coordinates of proteins with ~ 20 nm resolution.

11:40am **IPF-MoM11 Retinal Imaging with MEMS-based Adaptive Optics**, ***S. Olivier***, Lawrence Livermore National Laboratory **INVITED**

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Room: 312 - Session IPF+NC-MoA

Materials Imaging with Subatomic Resolution

Moderator: R. Ludeke, IBM (Retired), J. Murday, University of Southern California

2:00pm **IPF+NC-MoA1 Spatially Resolved Vibrational Imaging with Sub-Nanometer Resolution**, ***W. Ho***, University of California, Irvine **INVITED**

Vibrational spectroscopy has proven to be a powerful technique for chemical analysis, and its capability has been improved steadily over the years. At the limit of sensitivity is the detection of the vibration of a single bond and the imaging of such a signal would provide unprecedented spatial resolution in chemical visualization. In addition to revealing the chemical constituents at the atomic level, vibrational imaging at the sub-nanometer scale also can provide dynamical information such as charge and energy transfer, electron-vibrational coupling, and light-matter interaction. With the initial demonstration of inelastic electron tunneling spectroscopy and microscopy with a scanning tunneling microscope (STM), it is now possible to investigate with atomic scale resolution a wide range of inelastic phenomena that involve vibrational excitation. The scanning capability of the STM enables vibrational imaging of the interior of single molecules, their interactions with the environment, the coupling of electrons to vibrations in electron transport, and optical phenomena with atomic scale spatial resolution.

2:40pm **IPF+NC-MoA3 Attosecond Nanoplasmonic-Field Microscope**, ***M.I. Stockman***, Georgia State University, *U. Kleineberg*, Ludwig-Maximilians University, Germany, *M. Kling*, *F. Krausz*, Max Plank Institute for Quantum Optics, Germany **INVITED**

Nanoplasmonics deals with collective electronic dynamics, which arises due to elementary excitations called surface plasmons. Because of the very broad bandwidth, the surface plasmons undergo ultrafast dynamics unfolding on time scales as short as a few hundred attoseconds. So far, the ultrafast spatiotemporal dynamics on the nanoscale has been hidden from direct access in the real space and time. We propose an approach that will, for the first time, provide direct, non-invasive access to the nanoplasmonic dynamics with nanometer-scale spatial resolution and on the order of a few hundred attoseconds temporal resolution. This method combines photoelectron emission microscopy and attosecond streaking metrology. It offers a valuable new way of probing ultrafast nanolocalized fields in nanoplasmonic systems. This approach will be interesting both from a fundamental point of view and in the light of the existing and potential applications of nanoplasmonics.

4:00pm **IPF+NC-MoA7 Atomic Motion Observed with sub-Angstrom Resolution in the Electron Microscope**, ***P.E. Batson***, IBM T.J. Watson Research Center **INVITED**

The recent successful introduction of aberration correction optics into the electron microscope has produced an instrument that can routinely image the positions of single atoms and structure of small groups of atoms. In fact, the signal from a single atom is strong enough to obtain good quality images in a few tens of milli-seconds, allowing the taking of sequences of images to follow atomic processes. In the microscope, atomic level objects are vigorously excited by the electron beam, and this energy deposition is observed to speed up normal processes – island coalescence, structural changes, and nucleation of growth -- so that they are observable in relatively short times. In many cases, imaging in bulk specimens shows similar atomic level behavior. Thus stress relaxation and atomic redistribution within bulk structures may be observable in the presence of the electron beam, and so may be quantified if the electron beam interaction can be well understood. The combination of Electron Energy Loss Spectroscopy with atomic resolution imaging promises to obtain local electronic structure within the bulk, but changes in the bulk structure caused by energy deposition will complicate interpretation. This presentation will discuss these observations and suggest what types of mechanisms may contribute to the observed behavior.

4:40pm **IPF+NC-MoA9 Force Microscopy with Subatomic Resolution**, ***F.J. Giessibl***, University of Regensburg, Germany **INVITED**

A theoretical analysis of the factors that determine the spatial resolution of the force microscope led to the conclusion that optimal results are expected to occur when the oscillation amplitude of the cantilever in dynamic atomic force microscopy (AFM) has a magnitude similar to the range of the forces at play. When the cantilever is to oscillate with small amplitudes in a stable fashion under the influence of the field of the chemical bonding forces present between tip and sample, cantilevers with a stiffness of roughly 1kN/m instead of the commonly used 40 N/m are required.[1] Soon after these findings, experimental force microscopy data was published that shows "subatomic" resolution, that is the imaging of features within single atoms.[2] While these findings were debated, a direct comparison of scanning tunneling microscopy and AFM data showed that when probing a tungsten tip with a graphite surface (a "light-atom probe"), subatomic orbital structures with a spatial resolution of less than one Angstrom can be obtained in the force map, while a map of the tunneling current only shows the known atomic resolution.[3] Optimized subatomic contrast is obtained when recording the higher harmonics of the cantilever motion.[3] The idea of the light atom probe was carried further in a collaboration with the IBM Low Temperature STM group in Almaden, San Jose where an adsorbed CO molecule was used to probe the tip atom. It requires quite a large force to move a CO molecule laterally[4] and this molecule is an excellent probe for the orbital structure of the front atom of the metal tip. Ideally, one wishes to create a probe with a perfectly perpendicularly oriented CO molecule at the very end of the tip. First steps towards that goal will be discussed. We also address the question why "traditional" dynamic AFM has apparently not yet demonstrated subatomic resolution.

[1]F.J. Giessibl, H. Bielefeldt, S. Hembacher and J. Mannhart, Appl. Surf. Sci. 140, 352 (1999); F.J. Giessibl, Rev. Mod. Phys. 75, 949 (2003).
[2]F.J. Giessibl, H. Bielefeldt, S. Hembacher, J. Mannhart, Science 289, 422 (2000).
[3]S. Hembacher, F. J. Giessibl, J. Mannhart, Science 305, 380 (2004).
[4]M. Ternes, C. P. Lutz, C.F. Hirjibehedin, F.J. Giessibl, A. J. Heinrich, Science 319, 1066 (2008).

5:20pm **IPF+NC-MoA11 Cryolectron Microscopy of Biological Macromolecules on Its Way Toward Near Atomic Resolution and Multiple Conformations**, ***U. Luecken***, FEI Company, The Netherlands, *H. Zhou*, University of California, Los Angeles, *H. Stark*, Max Planck Institute of Biophysical Chemistry, Germany **INVITED**

I will report on the latest results just shown at the Gordon conference on Three dimensional Electron Microscopy and found teo of the world leading scientists in macromollecular complex imaging and Virus research.

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Marine/Terrestrial Imaging

Moderator: D. Zawada, USGS, Florida ISC

8:00am **IPF-TuM1 Imaging in the Underwater Environment: Current Status and Future Trends**, ***S.G. Ackleson***, Office of Naval Research **INVITED**

Natural waters are largely opaque to electromagnetic energy except for a narrow wavelength range between 400 and 700 nm - the visible light spectrum. If the water body, the ocean for example, contained only pure water, it would be possible to view objects through several hundred meters of path length. Unfortunately, natural waters are never pure, but contain large concentrations of suspended and dissolved matter that act to scatter and absorb light energy. The combined attenuation effects of scatter and absorption greatly reduce imaging range. The useful imaging range of conventional camera and flood light combinations is limited to between 1 and 2 optical attenuation lengths, translating to a few tens of meters in clear ocean water, but < 5 m in most coastal and estuarine environments. The development, over the last two decades, of laser-based systems employing synchronous scan and range-gated approaches have increased imaging range to 4 - 5 attenuation lengths and recent improvements in pulsed laser beam form and efficiency and signal processing techniques can potentially increase imaging range another 2 attenuation lengths. However, future improvements in underwater imaging will likely not be driven by better light sources and detectors or sensor architecture, but by how such systems are deployed. Advances in autonomous underwater platforms are allowing imaging researchers to think beyond traditional co-located source and detector approaches to scenarios where the imaging components are distributed within underwater sensing networks. Such approaches could potentially overcome limitations due to imaging range by using knowledge of local environmental variability and may provide opportunities to image across much greater ranges.

8:40am **IPF-TuM3 Coral Fluorescence Imaging**, ***C.H. Mazel***, Physical Sciences Inc. **INVITED**

Fluorescence in corals is optical alchemy, a magical transformation of ultraviolet or blue light to a rainbow of intense hues. Many marine organisms exhibit vivid fluorescence effects, a marvel of physics in action. Photography of coral fluorescence produces images of striking beauty that are also of great value for science. The biological function of the proteins that are the source of the fluorescence is not yet known, although there is no shortage of hypotheses – an aid for photosynthesis of the symbiotic algae, a sunscreen to protect against excessive ambient light levels, a way to preserve and intensify color in the wavelength-limited underwater environment, a beacon for prey. Photographs taken on the reef provide valuable clues that contribute to the scientific sleuthing. Whatever the function of fluorescence for the corals themselves, the phenomenon is a boon for reef science. Juvenile corals are very small (on the order of 1 mm) and are next to impossible to find in the complex surroundings of a reef. By diving at night with the right equipment many of these small corals can be excited to glow brightly, making them easy to find against the darker background. But not even reef scientists want to do all their work at night, and techniques have been developed to find and photograph fluorescing corals in the daytime without special shading. Corals are not the only marine organisms that fluoresce. The more scientists look, the more examples they find over a wide taxonomic range. In some cases the fluorescence signatures are distinct, and work has been done to perform computer classification of seafloor scenes based on the RGB representations of the fluorescence. Imaging is playing an important role in understanding the significance of fluorescence in the marine environment, and in putting the phenomenon to practical scientific use.

9:20am **IPF-TuM5 Deep Sea Bioluminescence**, ***E.A. Widder***, Ocean Research & Conservation Association **INVITED**

Bioluminescence occurs throughout the depth and breadth of the ocean. Organisms use light to find food, attract mates and avoid predators. An overview of bioluminescence will be provided along with an historical synopsis of methods of measurement. Emphasis will be placed on light producers most likely to impact underwater neutrino telescopes.

10:40am **IPF-TuM9 LIDAR in the Coastal Environment**, ***J. Wozencraft***, US Army LIDAR Bathymetry Technical COE **INVITED**

11:20am **IPF-TuM11 Streak-Tube Imaging and the Virtual Periscope**, ***B.E. Hubbard***, Areté Associates **INVITED**

This presentation will survey two distinct types of underwater imaging technology that have been developed in recent years for use by the military community. Areté Associates has developed and patented an innovative LIDAR technology that exploits the high spatial-temporal resolution of a streak-tube to generate extremely high-resolution 3-D images of scenes from a remote platform. This unique approach to 3-D imaging LIDAR enabled unrivaled object detection and classification in turbid media. Since then, Areté has developed several LIDAR systems for the mine countermeasures community that utilizes STIL technology to detect sea mines from air and underwater-borne platforms. Areté Associates' patented Virtual Periscope system enables underwater vehicles to image scenes from below the ocean surface without the need to raise a periscope. This technology improves stealth and mobility of the vehicle and reduces the risk of collisions with surface objects. The Virtual Periscope system uses a compact set of sensors and algorithms to measure and unwrap the image distortions caused by the wavy ocean surface.

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Frontiers in Physics
Moderator: F. Dylla, AIP

1:40pm **IPF-TuA1 Nano-Circuit Developments**, ***J. Gordon***, IBM Almaden Research Center **INVITED**

2:20pm **IPF-TuA3 Proton Cancer Therapy**, ***J. Flanz***, Massachusetts General Hospital **INVITED**

4:00pm **IPF-TuA8 Optical Atomic Clocks**, ***J. Ye***, National Institute of Science and Technology and University of Colorado **INVITED**

Quantum state engineering of ultracold matter and precise control of optical fields have allowed accurate measurement of light-matter interactions for the development of best atomic clocks. State-of-the-art lasers now maintain optical phase coherence over one second. Optical frequency combs distribute this optical phase coherence across the entire visible and infrared parts of the electromagnetic spectrum, leading to direct visualization and measurement of light ripples. An the same time, ultracold atoms confined in an optical lattice of zero differential a.c. Stark shift between two clock states allow us to minimize quantum decoherence while strengthen the clock signal. For ^{87}Sr, we achieve a resonance quality factor >2 x 10^{14} on the $^1S_0$ – $^3P_0$ doubly forbidden clock transition at 698 nm.[1] The uncertainty of this new clock has reached 1 x 10^{-16} and its instability approaches 1 x 10^{-15} at 1 s.[2] These developments represent a remarkable convergence of ultracold atoms, laser stabilization, and ultrafast science. Further improvements are still tantalizing, with quantum measurement and precision metrology combining forces to explore the next frontier.

[1] M. M. Boyd, T. Zelevinsky, A. D. Ludlow, S. M. Foreman, S. Blatt, T. Ido, and J. Ye, "Optical atomic coherence at the one second time scale," Science Vol. 314, pp. 1430 – 1433, 2006.

[2]A. D. Ludlow, T. Zelevinsky, G. K. Campbell, S. Blatt, M. M. Boyd, M. H. de Miranda, M. J. Martin, J. W. Thomsen, S. M. Foreman, J. Ye, T. M. Fortier, J. E. Stalnaker, S. A. Diddams, Y. Le Coq, Z. W. Barber, N. Poli, N. D. Lemke, K. M. Beck, and C. W. Oates, "Evaluation of a Sr lattice clock at 1x10-16 via remote optical comparison with a Ca clock," Science Vol. 319, pp. 1805 – 1808, 2008.

4:40pm **IPF-TuA10 Diamond Circuitry**, ***M. Lukin***, Harvard University **INVITED**

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Bold page numbers indicate the presenter